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Knowledge-based iterative model reconstruction technique in computed tomography of lumbar spine lowers radiation dose and improves tissue differentiation for patients with lower back pain

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ABSTRACT

Purpose: To evaluate the image quality and diagnostic confidence of reduced-dose computed tomography (CT) of the lumbar spine (L-spine) reconstructed with knowledge-based iterative model reconstruction (IMR).

Materials and methods: Prospectively, group A consisted of 55 patients imaged with standard acquisition reconstructed with filtered back-projection. Group B consisted of 58 patients imaged with half tube current, reconstructed with hybrid iterative reconstruction (iDose^4) in Group B1 and knowledge-based IMR in Group B2. Signal-to-noise ratio (SNR) of different regions, the contrast-to-noise ratio between the intervetebral disc (IVD) and dural sac (D-D CNR), and subjective image quality of different regions were compared. Higher strength IMR was also compared in spinal stenosis cases.

Results: The SNR of the psoas muscle and D-D CNR were significantly higher in the IMR group. Except for the facet joint, subjective image quality of other regions including IVD, intervertebral foramen (IVF), dural sac, peridural fat, ligmentum flavum, and overall diagnostic acceptability were best for the IMR group. Diagnostic confidence of narrowing IVF and IVD was good (kappa = 0.58–0.85). Higher strength IMR delineated IVD better in spinal stenosis cases.

Conclusion: Lower dose CT of L-spine reconstructed with IMR demonstrates better tissue differentiation than iDose^4 and standard dose CT with FBP.

1. Introduction

Plain radiograph for lumbar spine (L-spine) is the primary diagnostic imaging modality to evaluate patients with lower back pain but its radiation dose can be as high as 2.2 millisievert (mSV) in anterior-posterior view and 1.5 mSV in lateral view [1]. If additional oblique views are needed, overall radiation exposure can be higher [2]. Computed tomography (CT) of the L-spine has better sensitivity and specificity for evaluating discogenic pain [3]. Multiplanar reconstruction of L-spine CT also demonstrates bony structures such as facet joints, and soft tissue structures including intervertebral disc (IVD) and IVF better than conventional plain films [4,5]. However, the radiation dose of L-spine CT varies widely with different clinical scenarios and scan protocols, from 1.1 millisievert (mSV) to 19 mSV [6–8]. Concerns about lifetime risk of radiation-induced carcinogenesis and hereditary defects in young patients [9,10] have led to the widespread adoption of the ‘As-Low-As-Reasonably-Achievable’ (ALARA) principle in medical imaging. Recent applications of iterative reconstruction (IR) techniques dramatically decrease radiation dose compared with standard dose computed tomography (CT) reconstructed with filtered back-projection (FBP), maintaining equivalent image quality and diagnostic confidence with radiation doses as low as 3.44 mSV [7] and recent epidemiological studies have shifted to using lower dose L-spine CT as a standard imaging tool [7,11,12].

Abbreviations: CT, computed tomography; L-spine, lumbar spine; CNR, contrast-to-noise ratio; FBP, filtered back-projection; IMR, iterative model reconstruction; IR, iterative reconstruction; IVD, intervertebral disc; IVF, intervertebral foramen.

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IR decreases the increased image noise caused by lowering tube current or peak tube voltage. Earlier generations of hybrid IR such as $iDose^4$ minimized noise and artifacts primarily by using Poisson distributions of photon statistics and by taking into account fluctuations in x-ray influx, and blended FBP images with IR images to retain the texture or look of FBP images [13,14]. The latest generation of IR, including knowledge-based iterative model reconstruction (IMR) and model-based iterative reconstruction (MBIR), incorporates more accurate hardware information and system optics, and employs a variety of mathematical functions to achieve the desired image quality without blending FBP images [13,15,16].

Although earlier studies of imaging reconstructed with the latest IR have shown its clinical feasibility for several body regions [17–22], the image quality and diagnostic confidence of IMR in L-spine CT has not yet been explored. We therefore conducted this study to investigate whether lower dose L-spine CT reconstructed with IMR can maintain image quality and diagnostic confidence equivalent to that obtained with hybrid IR and standard dose L-spine CT reconstructed with conventional filtered back-projection (FBP).

2. Materials and methods

This study was conducted in a single tertiary referral hospital and approved by the local ethics committee (IRB number 2012-02-049B). Informed consent was obtained from all participating patients.

2.1. Patient selection

From December 14th 2014 to July 29th 2015, patients from the out-patient department referred for L-spine CT due to lower back pain were prospectively selected for this study. Patients who were below 18 years old, pregnant, reporting a psychiatric disorder, unable or unwilling to give informed consent, having metallic implants causing artifacts at L4-S1 level or whose data were incorrect or incomplete were excluded. After matching sex, age, and body mass index (BMI), 57 patients were excluded, while 113 patients were included and randomly assigned to either the standard radiation group (group A) or lower radiation group (group B).

2.2. Imaging acquisition

All examinations were performed using a 256-slice Brilliance iCT scanner (Philips Healthcare, Cleveland, OH, USA). After routine anterior-posterior and lateral scout radiographs, helical scans from the lower thoracic spine to the sacrum were performed with a field of vision (FOV) of 34 cm, a matrix size of 512×512, and a standard B filter. The exam aimed to evaluate bony structures as well as intra-spinal soft tissue and IVD. The radiation exposure condition was thus determined as follows [23–25]: for group A with standard radiation dose, 300 milliampere-second (mAs) tube current-time products with 120 peak kilovoltage (kVp) tube voltage were used; for group B, with lower radiation dose, 150 mAs tube current-time products with 120 kVp tube voltage were used to achieve a 50% radiation dose reduction. Based on Yang et al's publication and our pilot study, a 50% radiation dose reduction in combination with IR (both iDose 4 and iMR) was the lowest limit that our radiologists were prepared to accept. There was concern that further radiation dose reduction (>50%) might eliminate the advantage of IR in the contrast-to-noise ratio between the intervertebral disc and dural sac, and in the subjective grading of different anatomical regions. Therefore, we used a dose reduction of 50% in this study [7]. All patients received automatic tube current modulations based on their body geometry.

2.3. Imaging reconstruction

Images from group A, the standard radiation dose group, were reconstructed with FBP. Images from group B1, the lower radiation dose group, were reconstructed with a hybrid IR, $iDose^4$ level 4 algorithm (Philips Healthcare, Cleveland, OH, USA), sequentially by an automatic-programmed process over the CT console [7,26]. Images from group B2, the second lower radiation dose group, were reconstructed with knowledge-based IMR after the raw data from group B1 was transferred to a dedicated workstation (Philips Healthcare, Cleveland, OH, USA). There are several algorithms available for different body parts and IMR levels. In our pilot study, dose cascading evaluation was done and we confirmed that higher levels of $iDose^4$ and IMR could further reduce imaging noise. However, the imaging texture become unfamiliar and not acceptable for most radiologists when higher strength $iDose^4$ (>level 5) and IMR (2 or above) were used in the lumbar sacral region. Based on a consensus in our department during the trial period, we chose $iDose^4$ level 4 and IMR level 1 with a kernel of body routine for L-spine CT in our study.

Sequential multiplanar imaging reconstruction was performed with 3 mm thickness for both axial and sagittal planes.

2.4. Radiation dose

The volume computed tomography dose index ($CTDI_{vol}$) and dose-length product (DLP) were obtained from the final page of each examination, which was automatically generated by the system. $CTDI_{vol}$ in milligray (mGy) is a standardized measure of radiation dose output from a CT scanner, while DLP in milligray-centimeter (mGy-cm) is the product of $CTDI_{vol}$ and the scanned length. Effective dose (ED) was calculated by multiplying the DLP (mGy-cm) by a conversion factor ($0.0129\,mSv \times mGy^{-1} \times cm^{-1}$) [27].

2.5. Imaging analysis: objective quantitative measurement

Objective quantitative measurements were performed on a picture archiving and communication system (PACS) by a board-certified radiologist before subjective qualitative grading or diagnostic interpretation. Because most patients' symptoms came from anomalies at the L4-L5 and L5-S1 levels, and potential image quality deterioration started below the iliac bones, we focused our study at these two levels. At the L4-L5 levels, the mean density (MD) in Hounsfield units (HU) and standard deviation (SD) were measured at four regions of interest (ROIs), including the IVD, the dural sac, the right psoas muscle, and the cancellous bone of the L5 vertebral body (Fig. 1). ROIs were drawn as large as possible, avoiding obvious fat infiltration or prominent noise. The locations of the ROIs in the $iDose^4$ and IMR groups were matched according to the Shepp Logan (SL) numbers from their CT scans. The signal-to-noise ratio (SNR) of each area was defined as:

$$SNR = MD/SD.$$

To evaluate the interface between the IVD and the dural sac, we introduced the contrast-to-noise ratio between the IVD and the dural sac (D-D CNR), defined as:

$$D\text{-}DCNR = (MD_{IVD} - MD_{duralsac})/(SD_{IVD}{}^2 + SD_{duralsac}{}^2)^{1/2}.$$